APPLICATION FOR
UNITED STATES LETTERS PATENT

Title: Method and Apparatus for Force-Based Touch Input

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"Express Mail" Mailing Label Number ET365478138US

Date of Deposit: 4/13/2001

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Method and Apparatus for Force-Based Touch Input

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to concurrently filed and commonly owned patent application entitled "Tangential Force Control in a Touch Location Device," hereby incorporated by reference in its entirety.

BACKGROUND

Field of the Invention

The present invention relates to touch sensors and, more particularly, to force sensing touch location devices.

Related Art

The ability to sense and measure the force and/or location of a touch applied to a surface is useful in a variety of contexts. As a result, various systems have been developed in which force sensors are used to measure properties of a force (referred to herein as a "touch force") applied to a surface (referred to herein as a "touch surface"). Force sensors typically generate signals in response to the touch force that may be used, for example, to locate the position on the touch surface at which the touch force is applied. A number of particular implementations of this approach have been proposed, such as that described by Peronneau *et al.* in U.S. Pat. No. 3,657,475.

Such touch location is of particular interest when the touch surface is that of a computer display, or that of a transparent overlay in front of a computer display.

Furthermore, the need for small, lightweight, and inexpensive devices that are capable of performing touch location is increasing due to the proliferation of mobile and handheld devices, such as personal digital assistants (PDAs). The touch screens which perform this function may be built with a number of possible technologies. In addition to the force principle just mentioned, capacitive, resistive, acoustic, and infrared techniques are among those that have been used.

The force principle has some strong potential advantages over these competing techniques. Since force techniques may be applied to any overlay material, or indeed to the entire display itself, there is no need to interpose materials or coatings with low durability or poor optical properties. Also, since force is the basis of perceived touch, there is no problem with sensitivity seeming unpredictable to the user. With capacitive measurement, for instance, touch threshold varies with the condition of the user's skin, and with interposed materials, such as a glove. Stylus contact typically gives no response. With resistive measurement, threshold force depends upon the size of the contact area, and so is very different between stylus and finger. Acoustic measurement depends upon the absorptive characteristics of the touching material; and with infrared, a touch may register when there has been no contact.

In spite of these advantages of force-based technologies, resistive and capacitive technologies have dominated in the touch screen market. This reflects residual difficulties with known force techniques, which must be overcome to realize the potential of force technology.

Among these difficulties are:

- Excessive force sensor size -- especially width and thickness.

- Excessive sensitivity to transverse forces, leading to inaccuracy.
- Excessive force sensor cost and complexity.
- Excessive sensitivity to deformations of the touch surface or its supporting structure, leading to inaccuracy.
- The need to keep the touch surface mechanically independent of the application bezel that encloses the touch surface, which makes it difficult to integrate the touch screen into the larger structure, and makes it difficult to provide a good liquid and dust seal.

In modern touch applications, it is extremely important that provisions for touch force location and/or measurement not increase the size nor dictate the appearance of the touch-equipped device. This is especially true in portable and handheld applications. Conventional force sensors of the type required are typically much thicker than resistive or capacitive films, thereby potentially increasing the thickness of devices that incorporate such force sensors compared to devices that incorporate resistive or capacitive sensors. Since conventional force sensors of the type required cannot easily be made transparent, they cannot be placed in front of an active display area. As a result, devices including such conventional force sensors must typically be made wider than a resistive- or capacitive-based device to accommodate the force sensors. Thus force-based touch is potentially disadvantageous with respect both to overall device thickness and width, when compared to other kinds of conventional touch sensors.

Thus it is seen that the prior art fails to teach how force sensors may be made sufficiently narrow, thin, and inexpensive.

A touch force applied to a touch surface has both a component that is normal to the touch plane (the "perpendicular component") and a component that is parallel to the touch plane (the "tangential component"). The presence of a tangential component can introduce errors in the computed touch location. Various techniques for reducing the errors introduced by tangential forces are described in more detail in the co-pending application entitled "Tangential Force Control in a Touch Location Device."

In many applications it may be desirable for an application bezel to press firmly around the edges of a touch-equipped display or display overlay module. This arrangement provides a dust and/or liquid seal, and may also serve to stiffen and align the bezel. With force-sensing touch-location devices, however, the bezel does not typically rest directly against a force sensitive structure, since the variable handling forces thereby transmitted would interfere excessively with touch location accuracy. The prior art does not teach satisfactory methods for sealing, nor for sufficiently diverting bezel forces in force-based touch systems.

SUMMARY

In one of its aspects, the invention provides a novel capacitive force sensor. The sensor comprises a principal element, and an essentially planar support. The principal element combines the functions of elastic energy storage and one capacitor plate, and may be as simple as a plane rectangle of thin spring metal. As described in more detail below, the sensor may be implemented with a small number of mechanical parts and a very small capacitive gap, making the sensor easy and inexpensive to manufacture and making the sensor

particularly applicable for use in mobile and handheld devices. It should be stressed, however, that sensors made in accordance with the invention may be of great advantage in a wide range of devices, sizes, and applications. To date, they have been successfully used in devices with a working diagonal of from 4″ to 15″, and supported touch surface assemblies weighing from 0.6 ounces to nearly 4 pounds.

For example, in one aspect of the invention, a force sensor for sensing a touch force applied to a touch surface is provided. The force sensor comprises: a first element including an elastic element and a first capacitor plate having a first capacitive surface, the elastic element including at least part of the first capacitor plate; and a second element including a second capacitor plate opposed to the first capacitor plate; wherein transmission of at least part of the touch force through the elastic element contributes to a change in capacitance between the first capacitor plate and the second capacitor plate. Various other force sensors are also provided, as described in more detail below.

In yet another aspect of the invention, a force sensing touch location device is provided. The force sensing touch location device comprises: a touch surface; a bezel enclosing a first portion of the touch surface; and force transmission means including an enclosing portion enclosing a second portion of the touch surface, said force transmission means having a stiffness greater than that of the bezel, wherein the force transmission means includes a path to transmit force from the bezel to a region not including the touch surface.

In a further aspect of the invention, a force sensing touch location device is provided. The force sensing touch location device comprises: a touch surface defining a touch plane; a first rigid member; a contoured first film coupled to the touch

surface and the first rigid member to form a first seal therebetween, the contoured first film being compliant along an axis normal to the touch plane.

In another aspect of the invention, a method is provided for measuring a touch force applied to a touch surface using one of the force sensors described herein. The method comprises a step of developing a signal based on the change in capacitance between the first capacitor plate and the second capacitor plate of the force sensor. The amplitude of the signal may be a monotonic function of the change in capacitance between the first capacitor plate and the second capacitor plate. The method may include a step of measuring a property of the touch force, such as the amplitude of a component of the touch force that is perpendicular to the touch surface, based on the signal. 85. The method may include a step of measuring a location on the touch surface at which the touch force is applied.

In yet another aspect of the invention, a method is provided for separating a first capacitor plate from a second capacitor plate in a force sensor by a desired volume. The method comprises steps of: disposing a separator between a support surface and a principal element including the first capacitor plate to maintain a separation of at least the desired volume between the first capacitor plate and the second capacitor plate; coupling at least one region of the principal element to at least one region of the support surface; and removing the separator, whereby the first capacitor plate and the second capacitor plate remain separated by at least the desired volume in an unloaded state of the force sensor. The support surface may, for example, be the second capacitor plate.

In a further aspect of the invention, a method is provided for separating a first capacitor plate from a second capacitor plate in a force sensor by a desired volume. The method

comprises steps of: disposing a predetermined substrate containing particles of controlled size between a support surface and a principal element including the first capacitor plate to produce a separation of at least the desired volume between the first capacitor plate and the second capacitor plate; and coupling at least one region of the principal element to at least one region of the support surface to maintain the separation of at least the desired volume between the first capacitor plate and the second capacitor plate.

In another aspect of the invention, a method for manufacturing a force sensor is provided. The method comprises steps of: selecting a principle element including a substantially flat surface and a first capacitive surface; disposing the first capacitive surface in opposition to a second capacitive surface; and forming an elevated elastic feature into the substantially flat surface, whereby transmission of a force through the elevated elastic feature contributes to a change in capacitance between the first capacitor plate and the second capacitor plate.

In another aspect of the invention, a force sensing touch location device is provided. The force sensing touch location device comprises: a touch surface structure to which a touch force may be applied, the touch force including a perpendicular component that is perpendicular to a touch surface of the touch surface structure and a tangential component that is tangential to the touch surface of the touch surface structure; a supporting structure; at least one force sensor, in communication with the touch surface and the supporting structure, to measure properties of the touch force; lateral restraint means, in contact with both the touch surface structure and the supporting structure, for impeding lateral motion of the touch surface structure without substantially

impeding transmission of the perpendicular component of the touch force through the at least one force sensor.

Other features and advantages of various embodiments of the present invention will become apparent from the following description and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is an exploded drawing of a touch screen module of a first preferred embodiment, as might be used against the face of a separate LCD module.

FIG. 1B is a partial cross-section of the module of FIG. 1A, intersecting the center of a sensor.

FIG. 2 is a cross sectional view of a first embodiment, in a typical application installation.

FIG. 3 is a cross sectional view of a second embodiment, in a typical application installation.

FIG. 4 is a partially schematic cross-sectional view of a general touch-locating system, illustrating reduction of tangential force errors according to one embodiment of the invention.

FIGS. 5A through 5C provide partial cross sectional views illustrating the use of a flat suspension film or beam used as a lateral stiffening means.

FIG. 6 is a partial cross sectional view of a lateral stiffening and/or lateral restraint means with extended range of vertical motion, and directionally selective lateral stiffening.

FIGS. 7A through 7C are partial cross sectional views of further variations on the lateral stiffening means.

FIG. 8 is a partial cross sectional view of a touch system with a field-replaceable touch surface protector and liquid/dust seal.

FIG. 9A is a cross sectional view of a larger sensor of a type built in accordance with the invention.

FIG. 9B is an exploded perspective view of the sensor assembly of FIG. 9A.

FIG. 10A is a cross sectional view of a smaller sensor of a type built in accordance with the invention.

FIG. 10B is an exploded perspective view of the sensor assembly of FIG. 10A.

FIG. 11 is a vertically exaggerated cross section of a sensor variation employing a nonuniform gap, built in accordance with one embodiment of the present invention.

FIGS. 12A through 12D are plan views depicting possible variations in the outline and mounting arrangement of principal elements of sensors according to embodiments of the invention.

FIGS. 13A and 13B are vertically exaggerated cross sections depicting possible variations in the thickness distribution of principal elements of sensors according to embodiments of the invention.

FIG. 14A is a plan view of a sensor variation employing a principal element with simply supported ends, according to embodiments of the invention.

FIG. 14B is a side view of the plastic spacer used in the sensor variation of FIG. 14A.

FIG. 14C is a partial cross-sectional view of a touch location device employing variations of aspects of the invention, including the sensor variation of FIG. 14A.

FIGS. 15A and 15B are exploded and cross-sectional views, respectively, of a sensor variation incorporating nonmetallic elastic portions, according to embodiments of the invention.

FIG. 15C is a cross-sectional view of a related sensor variation incorporating nonmetallic elastic portions, according to one embodiment of the invention.

DETAILED DESCRIPTION

In one of its aspects, the invention provides a novel capacitive force sensor. As described in more detail below, the sensor may be implemented with a small number of mechanical parts and a very small capacitive gap, making the sensor easy and inexpensive to manufacture and making the sensor widely applicable, but particularly so for use in mobile and handheld devices. The sensor comprises a principal element, and an essentially planar support. The principal element combines the functions of elastic energy storage and one capacitor plate, and may be as simple as a plane rectangle of thin spring metal. The principal element is held in close parallel alignment with the essentially planar support by mechanical contacts at one or more bearing points or areas. These may be under the two ends of the rectangular principal element, though many other arrangements, such as cantilever, cross, disk, etc., will readily occur to one of ordinary skill in the art, and are within the scope of the invention. The support also bears a thin conductive region opposed to a portion of the principal element away from the contacts, which functions as a second capacitor plate, or counter electrode. The mechanical contacts may provide either simple, or clamped support to the principal element, viewed as a load bearing beam. The contacts however, should be designed to minimize dissipative or frictional effects. The principal element receives forces through an upper loading contact, at a point or area opposite the counter electrode. Components of force perpendicular to the support surface deflect the principal element so as to change the distance separating it from the counter electrode, thus altering the capacitance therebetween. If the mechanical contacts provide clamped end constraint, it is desirable that this be stiff; that is, most of the distance

change occasioned by a force should be due to flexure of the principal element, rather than twisting of the mechanical contact areas. Although cleanly elastic clamped end constraints may be tolerable, where they engender only a systematic change in sensitivity, better reproducibility and freedom from hysteresis usually may be obtained if the end constraints are stiff clamped end constraints, or fully flexible simple supports, such as pivots.

The essentially planar support surface may be part of an interconnect system, such as a printed wiring board or flexible circuit with appropriate stiffeners. The counter electrode may comprise a land, or foil, within the context of such an interconnect. The mechanical contacts may also constitute electrical contacts, and may be accomplished by soldering the ends of the principal element to other lands in the support plane.

Force may be measured as the ratio of an exciting AC voltage to the current it forces through the sensor. As a matter of practice, a constant current may be applied by a feedback circuit, and the exciting voltage measured (as in Roberts, 5,376,948); or a constant exciting voltage may be applied, and the reciprocal of the resulting current computed. The latter method may enable use of a somewhat simpler interconnect, and provides a somewhat more convenient opportunity for subtracting off estimates of fixed strays which might otherwise degrade linearity of response. The force-responsive signals derived from the force sensors may be processed to yield touch location information in accordance with principles known in the art.

The curvature resulting from flexure of the principal element is not ideal, but by confining the counter electrode to an area near the center of the principal element, potential

nonlinearities of response may be reduced to a level acceptable for use in a touch locating application. Other provisions for improved linearity may also be made, as described below.

A force sensor has a direction of sensitivity, such that a translational force of given magnitude creates greatest output when applied in that direction, and no output when applied at right angles to that direction. A displacement sensor has an analogous direction of sensitivity with respect to applied pure translational displacements. A force sensor is said herein to have an axis of sensitivity that passes through its elastic center in its direction of sensitivity. A displacement sensor may be taken to have an axis of sensitivity lying in its direction of sensitivity, and so located that relative rotation of the two sides about points in the axis tend to produce no output.

It is desirable that a force sensor have a precisely determined axis of sensitivity, and that this axis be easily and precisely aligned, as desired, with respect to the enclosing application. The thin, planar nature of the sensor provided in various embodiments of the invention satisfies this need naturally. It is also desirable for the force sensor to be unresponsive to any moment couples passing through it. For a force sensor comprising a displacement sensor sensing the displacement across an elastic means, this requires that the displacement sensor's axis of sensitivity pass through the elastic center of the elastic means. Sensors provided in various embodiments of the invention accomplish this goal by making the principal element and its contacts symmetrical under a 180 degree rotation about the axis of sensitivity.

Potential moment sensitivity may be further reduced by providing a rotational softener at the loading contact. A bump, or other elevated central feature in the principal element, may

serve as a pivot providing this function. Locating this feature in the principal element itself has the further advantage of providing the force sensor with a determined sensitivity. When force is transmitted from an overlying surface contacting the bump, changes in relative alignment leave the region of load transmission unchanged with respect to the force sensor.

Forces and moments may be transmitted through a sensor that are not those the sensor is intended to measure. If the sensor is not perfectly constructed and aligned, it may have some sensitivity to these, leading to errors of measurement. In addition, unmonitored forces and moments may be part of a pattern including monitored forces, such that the equations for locating touch may not be evaluated accurately without measurements of the full pattern being available.

Various aspects of the invention provide for the reduction or elimination of these unmonitored forces or moments.

In a first aspect, embodiments of the invention may employ a rotational softening means to reduce or eliminate moments transmitted through a force sensor. In one embodiment, such a rotational softener may comprise a soft elastic body, such as a small elastomeric slab, or a stiffer element, such as a portion of a metal stamping, bent or prolonged in the direction of sensitivity. In another embodiment, it may comprise a pivot, operating without receptacle against a hard surface, or with self-forming receptacle, against a softer surface.

One benefit of rotational softening may obtain where the touch surface structure is not fully rigid, such that some small local flexure occurs near a point of touch. Such local flexure may lead to substantial touch location error, even with perfectly constructed and aligned sensors, if the sensor on its support from below is not substantially softer in rotation than the attachment offered from above by the touch surface

structure. In effect, a sensor connection with excessive rotational stiffness can support a nearby touching finger in part by using the intervening portion of the touch surface structure as a cantilever, thereby obtaining more of the perpendicular force than would be ideally presumed. A distortion of the position of reported touch locations results, which distortion is sensitive to details of the stiffness relationships. Rotational softening may be employed to prevent the appearance of such a pattern combining unmonitored sensor moment with balancing spurious perpendicular force components.

Rotational softening may thus be of particular benefit when used with a touch surface structure that is thin and flat, and thus comparatively flexible, such as a flat overlay plate of minimal thickness.

Another benefit of rotational softening may obtain where the sensors are not perfectly constructed. Such sensors may give spurious responses to transmitted moments. A rotational softener may offer greatest reduction of the moment actually experienced by a force sensor, if it is located as close as possible thereto. This reduces the production of sensor moment in response to any lateral forces transmitted. Thus rotational softening achieving the benefits of the invention may be applied away from the plane of touch, and may be applied close to the force sensors.

In a second aspect, embodiments of the invention may employ a lateral softening means to reduce or eliminate forces transmitted through a force sensor at right angles to its nominal axis of sensitivity. In one embodiment, such a rotational softener may comprise an elastic body, such as a small elastomeric slab. In another embodiment, it may comprise a pin, column, or ball, offering a pair of pivots, softly

elastic ends, or rolling surfaces offset from each other by at least a small distance.

One benefit of rotational softening may obtain where tangential forces applied to the touch surface are prevented from developing a pattern of forces, such pattern combining spurious perpendicular sensor forces with lateral sensor force and moment to maintain overall equilibrium, as described in more detail below.

Another benefit of lateral softening may obtain where the sensors are not perfectly constructed. Such sensors may give spurious responses to forces at right angles to their nominal axis of sensitivity. Lateral softening may also reduce extra sensor moment potentially generated by such lateral forces, where the associated elastic center is not in the sensor center.

Combinations of lateral softening, rotational softening, and lateral stiffening may serve to establish necessary axes of sensitivity more accurately than can be achieved through the construction of the sensors themselves. This follows in part from the large area over which the alignment of the plane of effect of the lateral stiffening means may be established.

Many alternative embodiments of lateral and rotational softening means will be evident to those of ordinary skill in the art, and are within the scope of the invention.

The method of forming a force sensor from a principal element upon an essentially planar supporting surface provides striking advantages in simplicity and miniaturization.

In one embodiment of the present invention, where an essentially planar support surface is comprised of a printed wiring board or other planar interconnect system, a force sensor is provided that includes as little as one, single, separately manufactured and handled part - the principal element described above. For example, the principal element may be as simple as a

rectangle of plated spring steel, flat but for a small bump pressed into the center. Mounting may be accomplished by reflowing solder under the ends of the principal element, while the central region is spaced from the counter electrode area with a temporary stainless-steel shim.

Alternatively, the solder employed may be mixed with a small quantity of non-fusing particles of controlled size, and the presence of these may serve to establish the gap width during soldering. Surface tension of the solder may suffice to draw the opposing surfaces against the particles. Yet again, the principal element may be provided with areas of slight offset pressed or otherwise formed into the ends, and these may rest directly against the support. Such slightly offset areas may take many forms, one being a slight displacement of the entire end toward the support surface. Another entails forming one or more of the smallest practicable bumps at each end, protruding by the degree necessary to establish the desired gap. These offer some space under each end for good solder reflow, and also minimize the likelihood of trapped solder contaminants enlarging the gap.

Alternatives to the use of solder will be evident, including the use of cements, such as conductive epoxy, and methods involving independent or indirect electrical connection to the mounted element.

By allowing construction from starting materials that are inherently flat, smooth, and true, which are then simply spaced apart a small distance, various embodiments of the invention provide an extremely reliable and inexpensive method of achieving a very small capacitive gap. This small gap provides a high capacitance per unit area, which allows the sensor area to be very small. The small gap requires limited mechanical energy storage in the principal element, allowing the use of

thin material. The small gap implies high sensor stiffness, which in turn implies high resonant frequencies, and is beneficial for accurate measurement. The small area of the sensor means that flatness in the materials need be maintained over only a very short distance, thus making practical even smaller gaps in a virtuous circle of miniaturization.

Sensor designs provided by various embodiments of the present invention are subject to a simple scaling rule over fairly wide range of sizes. A new design may be produced, which is N times shorter, N times narrower, and N squared times smaller in gap. If the original proportions and material thickness are otherwise retained, the resulting sensor will retain the same capacitance, force range, and sensitivity as the original. Since the area is N squared times smaller and the gap N squared times smaller, the capacitance is the same. Since the spring rate is N squared times greater and the gap N squared times smaller, the relative capacitance change with force, i.e. the sensitivity, is the same. Since the stressed portion of the principal element is N squared times smaller in volume, but stores N squared times less energy for the same applied force, it is exposed to the same stress levels. Since the deviation of a warped surface from flat, scales as the square of the distance over which the deviation is taken, the flatness requirement for the materials used is unchanged. Note that "flatness" here refers to deviations of low spatial frequency; high frequency failures of smoothness may ultimately limit miniaturization scaled this way. It may be noted, however, that ordinary spring steel and circuit board materials are smooth enough to support gaps down to 1/1000 of an inch, and probably substantially smaller.

In another of its aspects, the invention provides a novel means for performing accurate touch location measurements in the

presence of tangential forces, even when the sensors are located well behind the plane of touch. This is accomplished with lateral stiffening means, which direct tangential touch forces away from the force sensors (e.g., to the surrounding support structure). At the same time, perpendicular touch force components pass predominantly through a mechanically separate path to the force sensors. The lateral stiffening means is typically designed to have a plane of zero reaction moment to tangential forces, which is co-incident with, or close to, the touch surface. In cases where lateral stiffness through other force paths is not insignificant, the lateral stiffening means may be designed to achieve the same net effect for all paths collectively.

To simplify the design, and maximize reproducibility, force paths other than the lateral stiffening means may be provided with explicit lateral softening means, such that essentially all tangential forces pass through the lateral stiffening means. The perpendicular force path through the sensors may be stiff, while the perpendicular force path through the lateral stiffening means may be soft. The latter is particularly desirable in circumstances where interfering perpendicular displacements may occur across the lateral stiffening means, as might result from flexing in an overlay plate or its surrounding frame. Together, both provisions accomplish full segregation of the tangential and perpendicular touch forces into separate paths.

The lateral stiffening means may, for example, be embodied in a thin member or film, which joins a display or touch overlay to a surrounding frame. This film may bridge a small gap between the frame and the edge of the touch surface, where it attaches, or there may be a lesser gap, and the film may carry above the touch surface a short ways before attaching to the

touch surface. By being much thinner than it is broad, yet composed of material of fairly high modulus, this film may be stiff to tangential movement of the touch surface, yet soft to perpendicular motion. The film may be made to bulge, or curve, somewhat above and/or below the touch plane, thus increasing its vertical range of compliance. Such curvature also has the effect of restricting the lateral stiffening to the sides parallel to a tangential force, where it is transmitted through the film as shear, rather than compression or extension.

A lateral stiffening means, embodied as a complete circumferential edge film in or close to the plane of touch, may at the same time constitute a liquid and/or dust seal.

Although in the embodiment described above the lateral stiffening means is a thin member or film, this does not constitute a limitation of the present invention. Rather, the lateral stiffening means may take a variety of forms and be constructed from a variety of materials. The lateral stiffening means need not be continuous, and is not limited to any particular modulus, aspect or shape. Rather, the lateral stiffening means may include any structure that performs the function of lateral stiffening as described herein.

In another aspect of the invention, a thin or slender member or set of members may comprise a lateral restraint means, allowing assembly of a force-sensing touch-location device to be maintained, without strong attachments that fix the support surface structure by paths passing through the force sensors. In such a device, the exact perpendicular operating position of the touch surface structure is established by perpendicularly stiff paths, such as through the force sensors, that provide connection to the support structure independent of the lateral restraint means. In one embodiment, the touch surface structure may rest upon force sensors below, without attachment, and

without any special receptacle or other provision on the touch surface structure for receiving contact with the force sensors, or needing careful alignment thereto. The force sensors, whether mounted from the touch surface structure above, or from the support structure below, may thus be provided with rotational softeners and/or lateral softeners offering little or no strength but in compression. Many forms of curvature or elevated feature from either side at the perpendicular force contacts may serve as a rotational softener, so long as local touch surface flexure does not translate the point of contact by more than the tolerable error in touch location. Perpendicular contact may be maintained by preload means, which may be separate from the lateral restraint means.

A lateral restraint means may be distinguished from a lateral stiffening means in that tangential touch forces may not necessarily pass through a lateral restraint means. The small, incremental forces of a touch may instead follow stiffer paths through the force sensors or other connections, as dictated by friction. Larger lateral disturbances, however, overcome friction and cause minute sliding motions in these paths. These disturbances may comprise jolts in shipping and handling, for instance, or for large devices with a heavy touch surface structure, changes in orientation with respect to gravity. A lateral restraint means may absorb the brunt of such disturbances tangentially, protecting the touch device structure, function, and accuracy from significant alteration. By reaching the upper limit of its perpendicular motion, a lateral restraint means may also absorb a disturbance tending to lift the sensors free of contact, although such function may be performed by separate outward limit stops. A lateral restraint means may deflect far enough to be assisted by lateral limit stops during large, temporary forces, but when these cease, it

may restore satisfactory centering, free of continuing interference from stops.

A thin member or set of thin members may provide a lateral restraint means that is simple and compact. It may add little or nothing to the thickness of a touch-location module or touch-enabled display module. Such a thin member or set of members may further offer a favorably high ratio of lateral to perpendicular stiffness. Absent such a high ratio, members sufficiently robust to provide good lateral restraint may offer excessive vertical stiffness. In avoiding such excessive vertical stiffness, various embodiments of this aspect of the invention avoid inaccuracy occasioned by parasitic force paths, such as might pass through a seal. They also avoid the need for an excessively thick and stiff touch surface structure or support structure in mitigation. Such thin members may flex softly in response to perpendicular displacement of the touch surface, but stiffly resist tangential displacement. Thus, a wire-like member, inclined at most shallowly to the plane of touch, may serve to resist tangential forces primarily through end-on compression and extension, while being softly flexible in transverse beam bending. So too, a sheet-like member may transmit tangential force stiffly in shear, and possibly also in compression and extension, while responding to perpendicular displacement of the touch surface with soft beam bending transverse to its breadth. Where tangential force transmission is confined to shear, and where a lateral restraint means is not also a lateral stiffening means, sheet-like members may provide an effective lateral restraint means, even though they incline steeply to the plane of touch. A lateral restraint means may perform its function, even if not located in the plane of touch.

In another aspect of the invention, a thin frame means is wrapped closely around the periphery of the overlay or supported

display. A major benefit of this construction is the provision of a module which handles, mounts, and integrates with its surrounding application in a manner which is familiar from other touch technologies, is accepted, and is convenient. The frame means serves to divert perpendicular forces from the application bezel normally present, so that there is no danger of interference with the touch surface. The frame lip provides a convenient rigid bearing edge to receive both a vertically compliant seal passing outward from the touch surface, and a smooth surface or other seal provision of the underside of the application bezel. Since perpendicular forces are of principal concern, a very thin vertical frame leg, embodies an application bezel support member, and serves to carry bezel forces back to a stiff surface behind a touch module, such as the surface of an LCD. With greater section depth, such a very thin leg also serves to carry back bezel forces when the frame surrounds a supported LCD.

FIGS. 1A-1B present a touch sensitive transparent overlay module 101 including capacitive force sensors according to a first embodiment of the invention. The module 101 may be used to sense touches applied by, for example, a finger, stylus, or other object. As described in more detail below, in various embodiments of the present invention, the module 101 may be used to sense properties of a touch force applied to a touch surface, such as the location at which the touch force is applied to the touch surface and/or the magnitude of a component of the touch force that is perpendicular to the touch surface.

The transparent overlay module 101 is proportioned as might be appropriate for use on an LCD display with a diagonal of 4 inches, though proportions and variations for other displays of other sizes will be apparent to those of ordinary skill in the art. Transparent panel 102, carrying touch surface 103a, rests

within frame 104a. Captured between panel 102 and frame 104a are interconnect flex print 105, force sensor principal elements 106, and lateral softening means 107. Preload springs 109 are fastened to the edges of panel 102 with cement 110. The ends of springs 109 engage holes 112 in frame 104a when assembled, thereby applying a total compression of approximately two pounds to the structures captured between panel 102 and frame 104a. The flexed positions of springs 109, as assembled, place them in straight lines along the short edges of panel 102. Member 108 is a combination lateral stiffening means, lateral restraint means, and liquid/dust seal 108. Member 108 may also be referred to elsewhere herein simply as a lateral stiffening means, lateral restraint means, or seal, for ease of explication. Member 108 adheres to panel 102 and to the outer surfaces of the vertical flanges of frame 104a, thereby securely centering panel 102 within frame 104a. When so centered, there is a small space between the long sides of panel 102 and frame 104a, and there is a small space around the nonattached portions of springs 109. Thus forces applied to touch surface 103a can produce small perpendicular motions of panel 102 without occasioning interference or scraping around its edges.

One embodiment of the capacitive force sensor of the present invention is now described in more detail. As will become apparent from the following description, FIG. 1A illustrates four capacitive force sensors in assembly and FIG. 1B illustrates one of these capacitive force sensors in cross-section. In assembly, interconnect 105 is threaded through apertures 111 in frame 104a and dressed along and above opposing horizontal flanges of frame 104a as shown. Interconnect 105 is fastened securely to frame 104a under receiving regions of principal elements 106, such that these regions achieve the effective stiffness of frame 104a. Such attachment may be

achieved by providing interconnect 105 with backside lands which are soldered to frame 104a, or by cementing interconnect 105 to frame 104a with epoxy resin, or by other known means. Elements 106 are secured to interconnect 105 by soldering their ends to lands 113. By either the shape of principal elements 106, or by the assembly process which attaches them to interconnect 105, there remains a small gap of determined width between principal elements 106 and counter-electrode lands 114. For the type of assembly shown, this gap may be 0.0010 inch. A central dimple, or force bearing 121, is pressed upward into each of principal elements 106.

Each of the force sensor principal elements 106 combines the functions of spring and capacitor plate. As perpendicular force is applied to one of the bearings 121, flexure of the corresponding one of the principal elements 106 increases the capacitance between the central portion of the principal element's underside and the corresponding one of the counter-electrodes 114 (which are on the underside of interconnect 105). This change in capacitance may be measured to measure the force applied to the surface 103a. As shown in FIGS. 1A and 1B, each bearing 121, corresponding principal element 106, the corresponding receiving region of interconnect 105, and the stiffening support provided thereto by frame 104a, thus together constitute a force sensor.

Although four force sensors are shown in FIG. 1A, it should be appreciated that any number of force sensors may be employed with a particular device as may be appropriate for a particular application. Furthermore, although the force sensors are positioned close to the corners of the overlay panel 102, this is not a limitation of the present invention.

Although a particular embodiment of the principal element 106 is shown in FIGS. 1A and 1B, more generally principal

element 106 is an electrically conductive elastic element that both stores elastic energy and acts as a capacitor plate in a force sensor. As a result of the principal element's elastic properties, the principal element 106 is deflectable by a touch force applied to the touch surface 103a. This deflection causes a change in the capacitance between the principal element and lands 113 (which act as capacitor plates that oppose the principal element 106). The principal element 106 thereby combines the functions of elastic energy storage and a capacitor plate in a small, thin, easily manufactured part.

Interconnect 105 provides electrical access to counter-electrodes 114 and to principal elements 106 via lands 113, as necessary to provide separate readings from the four force sensors so constituted. In one embodiment of the present invention, each of the principal elements 106 is the only component of each force sensor that must be manufactured and handled individually.

In embodiments of the present invention such as that depicted in FIGS. 1A-1B, lateral softening means 107 may comprise small punched disks of stainless-steel tape, backed by a typically soft acrylic adhesive. The adhesive surfaces are applied to the backside of panel 102, such that the metal surfaces press against bearings 121 after assembly. The effect of the small area of soft acrylic adhesive, so confined, is to substantially reduce the lateral forces generated between principal elements 106 and panel 102, generated in reaction to tiny lateral displacements of the under surface of panel 102.

As described above, in one embodiment each of the principal elements 106 is provided with a bearing 121. The bearing 121 may provide a region of load transmission from the touch surface 103a to the corresponding principal element 106. Although the bearings 121 are shown as small bumps located at the centers of

the principal elements 106, it should be appreciated that other elevated features may be provided in the principal elements 106 to perform the same function.

The bearings 121 may serve as pivots. Locating the bearings 121 in the principal elements 106 themselves has the advantage of providing the force sensor with a determined sensitivity. When force is transmitted from an overlying surface (such as the touch surface 103a) contacting one of the bearings 121, changes in relative alignment of the corresponding one of the principal elements 106 and the overlying surface (e.g., the undersurface of panel 102) leave the region of load transmission substantially unchanged. This effect becomes more pronounced as the size of the bearings 121 and the corresponding region of contact decreases. Note that, as shown in the embodiment shown in FIG. 1B, the bearings 121 need not be disposed within receptacles.

Further details appropriate for the embodiment depicted in FIGS. 1A-1B may now be considered. Frame 104a may be of mild steel, plated or coated for corrosion resistance. It may be made from 0.020 in. sheet, stamped, folded, or drawn by any of a variety of known techniques. Frame 104a may have flanges around 1/8 in. wide. Panel 102 may be of either clear plastic or of glass. If of glass, it may be around 0.050 in. thick. Preload springs 109 may each be a round steel wire, 0.029 in. in diameter, and 0.080 in. longer than the matching side of panel 102. In order to adopt the correct straight form when assembled, each of springs 109 may be given an unloaded curvature, which from a nil value at the spring's ends, increases linearly towards the center of the spring where it is attached to the panel 102.

Lateral stiffening means 108 may comprise, for example, a polyester or polyimide film, 0.001 to 0.002 in. thick, with

acrylic adhesive on the under surface in two areas where attachment is desired. The first such adhesive area 118 lies along the outer portion of 108 beyond the dashed line, which portion folds down over the vertical flanges of frame 104a. The second adhesive area 119 lies in a strip about 1/16 in. wide around the inner edge of 108. This area adheres to touch surface 103a slightly in from the edge of panel 102. The stress in lateral stiffening means 108, when bent along the dashed line, may be relieved, and lateral stiffening means 108 may thereby be given a proper final contour, by a simple thermoforming operation. This may be performed either before or after assembly. The excess material at the external corners of lateral stiffening means 108 may be folded along the diagonal, and laid over to the side against the vertical flange of the frame 104a. The suitable breadth of the freely flexing region 120 of lateral stiffening means 108 depends upon its own stiffness, upon the stiffness of panel 102, and upon the accuracy required. It may, for example, be in the range of 0.060 to 0.120 in. It should be appreciated that the particular embodiment of the lateral stiffening means 108 depicted in FIG. 1A is provided merely for purposes of example and does not constitute a limitation of the present invention. Rather, lateral stiffening means 108 may include any structure or structures that limit lateral movement of the panel 102 in response to touch forces.

In environments where accurate touch location is required on a moving or shaking display, accelerometers 115a-b may be employed. Accelerometers 115a-b may be rectangles of stainless or spring steel shim stock 1 mil thick, 0.120 in. wide, and 0.250 in long, plated for solderability. In the embodiment depicted, accelerometers 115 are soldered to lands 116, so that they carry over lands 117 as simple cantilevers, with capacitive

gaps of about 2 mils. Any number of accelerometers may be used. For example, as shown in FIG. 1A, the two accelerometers 115 are symmetrically positioned on opposing sides and are connected in parallel. The resulting single channel of Z-axis acceleration may then be measured capacitively, and the results applied to correct the force sensor channels as taught in Roberts 5,563,632. Alternatively, three or four accelerometers driving separate sensing channels could be used, for example, to encode X and Y rotational accelerations, as well as the typically larger acceleration of Z displacement. Since the magnitude of correction required is generally modest, however, such refinement may not be necessary in particular embodiments. Where one accelerometer suffices, it may also be placed externally to module 101, such as on an accompanying application circuit board. Such mounting may be parallel to the touch plane, and may be centered approximately under the centroid of the touch surface. As with the principal elements of the force sensors, the accelerometer elements may be constructed in variations with other shape than rectangular. They may be manufactured and assembled by many of the same techniques as may be applied to the force sensors.

Since panel 102 is not secured via the force sensor or the preload springs 109 in the embodiment depicted in FIG. 1A, lateral stiffening and restraint means 108 is employed both in its lateral restraint aspect to maintain basic geometry, and in its lateral stiffening aspect to define dynamic lateral stiffness. Note, however, that lateral softening means 107 may be used even though panel 102 has the potential to slide by tiny amounts with respect to the sensors beneath. Preload forces, in addition to the touch force itself, may create sufficient friction to prevent any plausible tangential force from causing such sliding during a normal touch. It is, therefore, the ratio

of the lateral stiffness of lateral stiffening means 108 to that of the sensor assemblies only in the differential sense for small forces that cause no sliding which determines the path taken by tangential touch forces.

Although lateral stiffening means 108 is depicted in FIGS. 1A-1B as a single piece of material, this is simply an example and does not constitute a limitation of the present invention. For example, lateral stiffening means 108 may be assembled with 4 tape segments, butted or overlapped in any of various ways at the corners. Alternatively, lateral stiffening means 108 may be, for example, a single sheet of transparent film, attached with an optically clear adhesive over the full interior area of touch surface 103a. Lateral softening means 107 may include a thin layer of a tough but soft elastomer, such as natural rubber. However, the simpler choice of soft acrylic adhesive has proven sufficiently tough and compliant, in spite of being somewhat thinned in the bearing area when the foil is only 0.0015 in. thick. Panel 102 may be detailed at its edges, especially if made of plastic. For instance, holes parallel to the surface near the corners of the panel 102 may retain angled preload spring ends, with hooks bent inward from frame 104a to hold the preload springs at their centers.

FIG. 2 presents touch overlay module 101 as it might be employed within a typical application device 201. Application enclosure 202 includes bezel 203, carrying alignment feature 204 on its inner surface. Alignment feature 204 may, for example, be continuous, comprise periodic isolated protrusions, or comprise the ends of periodic stiffening ribs. In addition to touch overlay module 101, enclosure 202 contains LCD display module 205, and application electronics 206. LCD 205 and electronics 206 may be retained and positioned by standoffs as depicted here for diagrammatic simplicity, or by engagement with

molded details in enclosure 202. Touch module 101 may be retained, centered, and aligned with respect to the display surface of LCD module 205 by the pressure of bezel 203, in conjunction with feature 204 and the rigid support provided by LCD 205. When so retained, upon opening enclosure 202, touch module 101, and perhaps the other internal components, may be freely separated. Alternatively, touch module 101 may be permanently or semi-permanently fastened to LCD module 205 by such means as cement, or acrylic transfer adhesive, applied between frame 104a and the surface of LCD 205. In this instance, feature 204 may be omitted, or may be employed to better center the visual opening of bezel 203 by slightly flexing the sides of enclosure 202.

The horizontal flanges of frame 104a may receive support from LCD module 205 by engaging either portions of the bare LCD glass, portions of the polarizer covering that glass, or portions of the partial metal enclosure which typically wraps around the edges of LCD module 205. The highest surface encountered by frame 104a will determine the source of support. The entire horizontal flange width of frame 104a need not be engaged to provide satisfactory support, but touch module 101 and frame 104a may be sized such that engagement occurs in the same plane around all, or nearly all, of the periphery of touch overlay module 101. Small gaps in the support of frame 104a are tolerable, but large gaps in support along the length of 104a are preferably, but not necessarily, avoided.

Note that the application of touch module 101 to the surface of LCD module 205 generates gap 207. Some space (represented by gap 207) may be required for proper operation of touch module 101 so that vertical displacements of panel 102 created in normal touch operation do not transfer forces by contact of panel 102 to LCD 205. Gap 207 may also be provided

because of the fact that pressure applied to the surface of an LCD module often results in unpleasant visual effects, due to displacement of the image-forming fluids within the LCD. Finally, routine or heavy compression of the LCD surface may lead to damage, called "bruising". Avoidance of such bruising may require a larger size of gap 207 than that used to satisfy the previously stated considerations.

If, however, the size of gap 207 as otherwise implied by the construction of touch module 101 is greater than desired, simple variations of the embodiment depicted in FIG. 2 may be used to reduce the size of gap 207. In particular, a ledge or step in the back surface of panel 102 around its edge may be used to engage the force sensors at their usual height, and provide clearance from frame 104a, while lowering the back surface of panel 102 over the display area of module 205, thus narrowing gap 207. Touch surface 103a may be left in the original plane, thus occasioning greater thickness of panel 102 over the bulk of its area. Alternatively, touch surface 103a may also be lowered somewhat, and the overall height of module 101 thereby reduced. This is made possible by the fact that the strength and stiffness of panel 102 are related principally to the central portion of its area.

In a second embodiment of the invention, a force sensing touch location device is provided in which a surface of an LCD - rather than an overlay panel (such as the overlay panel 102 shown in FIG. 1A) - serves as the touch surface. For example, the actual display panel of an LCD assembly may replace the overlay panel 102 in the touch sensitive transparent overlay module 101 shown in FIGS. 1A-1B. The display panel and possibly other internal components of the LCD assembly may then be supported by principal elements 106 in conjunction with lateral stiffening means 108. The force sensors based upon principal

elements 106 may thus be displaced considerably farther from the touch surface in such an integrated touch LCD than in the transparent overlay module 101 shown in FIG. 1A; however, the combined use of lateral stiffening means 108 with lateral softening means 107 may be used to prevent the introduction of tangential force errors.

As compared to the transparent overlay module 101, the touch LCD embodiment described above may benefit from improved optics, reduced overall thickness, and reduced parallax. Improved optics result primarily from removing two of the three solid/air boundaries potentially requiring antiglare treatment. Reduced thickness may result from eliminating gap 207 and merging of panel 102 with the top-glass of the LCD display to form a single glass layer of less aggregate thickness. Since these thickness reductions move the touch surface closer to the image-forming layer of the LCD, there is also a reduction in touch parallax.

Although, as previously stated, many LCDs are not appropriate for direct application of touch, some are; and the designs of others may be altered for direct application of touch in combination with the second embodiment of the invention described above. Such alterations may include, for example, a slight thickening of the LCD front glass.

Referring to FIG. 3, a self-contained, touch-enabled LCD module 305 is shown according to the second embodiment of the invention. The differences between touch LCD 305 and touch module 101 are best exemplified in the cross-sectional diagram of FIG. 3, which also exhibits a typical containing application device 301.

Touch LCD 305 comprises frame 104b, LCD electronics board 304, light diffuser 303, LCD display panel 302, principal elements 106, lateral softening means 107, and lateral

stiffening means 108. Furthermore, preload springs similar in function to springs 109 are also present, but do not show in the plane of section. Frame 104b does not require a clear visual opening and so may close across the back of touch LCD 305, shielding, stiffening, and protecting it, and in other ways subsuming some of the functions of a conventional LCD module frame. Frame 104b, though still of thin material, here has substantially greater section depth than frame 104a, and so does not include support from behind, continuously or nearly continuously around its periphery, as frame 104a does in module 101. A separate interconnect 105 is no longer present, as its function is subsumed by LCD electronics board 304. Board 304 is firmly supported against frame 104b in the immediate vicinity of each of the principal elements 106. However, depending upon the thickness of board 304, the firm support may not require bonding sufficient to stiffen board 304 under principal elements 106. The goal must be to achieve sufficient net stiffness under principal elements 106 that the end constraint, in this sensor embodiment, is essentially a clamped end constraint. In particular, the residual elasticity of the end constraint should be sufficiently small and/or reproducible that the behavior of the force sensor is not rendered unpredictable.

In the variation depicted in FIG. 3, diffuser 303 and display panel 302 interlock, or are otherwise so attached, as to travel together for purposes of positioning and force transmission. They are supported - in a manner similar to panel 102 of module 101 - by lateral softening means 107, coupling to bearings 121 of principal elements 106; and by lateral stiffening means 108.

Note that diffuser 303 is depicted with shallow bosses extending downward to establish contact with the force sensors. This is because the force sensing assemblies will generally be

thinner than the thickest components mounted to board 304. In other variations, the diffuser 303 may be carried with board 304 and move independently of display panel 302. Perpendicular forces applied to panel 302 are then transmitted back to the force sensors through columns, bosses, or tabs extending between. These roughly columnar structures may have sufficient flexibility in both transverse directions to perform the same function as lateral softening means 107, obviating the need to entrain a thin layer of soft material as previously depicted. Such columnar structures may be molded as part of the same component comprising diffuser 303, being softly connected thereto by thin molded connections.

Display panel 302 may connect to electronics 304 with either flex cable, or a sufficiently compliant elastomeric connector. If the connection is hard-docked, as with screws, a cantilever tab may be routed into the edge or interior of the PC board of 304 to carry the connection with sufficient perpendicular compliance.

Various embodiments of the invention employ no permanent connection between the force sensing assemblies and the floated structures they support, whether overlay plate or display components. This simplifies assembly, relaxes requirements for precision and dimensional stability, and provides a simple means whereby the force sensors may be protected from unwanted rotational sensitivities. In such embodiments of the invention, provision may be made to establish a static perpendicular preload force to keep the floated components firmly seated against the force sensors during all ordinary conditions of operation.

In one embodiment of the invention, the preload means apply sufficient total preload force, are possessed of a sufficiently low spring constant, do not provide unwanted lateral stiffening

significantly removed from the plane of touch, and are coupled to the floated components with sufficient symmetry to preload the sensors more-or-less equally.

In various embodiments, a minimum sufficient preload force may be established by factors including but not limited to the following. If it is desired that the touch apparatus operate in any orientation, a total preload force may be provided that exceeds the weight of the floated overlay plate or display components. In the case of large, statically mounted displays, this may be the main consideration. In other cases, other total preload forces may be provided if particular resistance to vibration and/or enclosure torsion is desired. In automotive applications, for instance, the need to avoid buzzing under at least several g's of vibration may lead to use of a total preload force of at least several times the floated weight. In all applications, there is the potential for unsymmetrical loading, as may occur when the application enclosure is seated against an uneven surface. This can lead to torsion extending to frame 104a, such that the corners of frame 104a no longer lie in a common plane.

Modest preload forces prevent torsional problems with touch module 101. This is due to the relative flexibility of plate 102 -- which is generally made as thin as possible -- and to the stiffness of the underlying LCD. Greater preload forces, and/or a surrounding structure more resistant to torsion may be used with touch LCD 305.

In one embodiment, the preload force changes very little as a function of ordinary touch displacements, in order that essentially all of the perpendicular force change occasioned by a touch may pass through the sensor assemblies. Thus, the preload force may be applied by elastic means which, in use, are deflected a long distance from their unloaded state. The "long

distance" in question is considered in comparison to the distance through which the preload force deflects the common path shared by both the preload force and perpendicular touch forces. In one embodiment, each of the preload springs 109 of module 101 applies a total force of about 1 lb. when its ends have been flexed through the approximately one inch displacement required to place them in assembled position. For example, a touch close to the location at which the spring 109 is attached by cement 110 shares the maximum common path with the preload force -- conversely, it tends to generate the greatest flex in preload spring 109. For a one pound touch force, the deflection generated at the location of cement 110 is not more than a few thousandths of an inch, the great bulk of which occurs in panel 102 itself, rather than in principal elements 106. Since the preload force is a roughly linear function of preload spring deflection, it can be seen that well under 1 percent of the perpendicular touch force is diverted through springs 109, and therefore "not seen" at the force sensors.

Since the ends of springs 109 press upward against the inner surfaces of holes 112 at points very close to the plane of touch, it is immaterial that springs 109 may provide significant additional lateral stiffness against displacements parallel to their length. Other embodiments of the preload springs 109, however, with an end or ends retained significantly out of the plane of touch, might include some ancillary lateral softening means.

Alternatively, in other embodiments, preload spring may be applied along all four edges of an overlay or other touch surface structure, and by appropriate attachment of their ends, serve also as either lateral stiffening means or lateral restraint means. Furthermore, such springs may be located wholly or in part below the touch surface. With an appropriate

shallow sigmoid shape, and supporting ends attached somewhat below centers affixed to the touch surface structure, such springs may further comprise a lateral stiffening means in accordance with an angled stiffness structure, as described in the co-pending application entitled "Tangential Force Control in a Touch Location Device."

Touch LCD 305 may be preloaded with a design identical to that of touch module 101. Free access to areas behind the display panel 302, however, creates other opportunities for locating the preload means. A single spring, for instance, might be attached to the back of the LCD panel 302 near its center. A spring wire, having the assembled shape of a "Z", might attach at its ends to the frame sides, and at its center to the back of the LCD panel 302. A nearly closed "C" shape might connect at its ends between the opposed centers of the frame back and of the floated assembly. Many other variations will be apparent to those of ordinary skill in the art. Note that the preload spring attachments may be well removed from the plane of touch; therefore the shape of the spring may allow relatively soft flexure in all directions, in which case additional lateral softening may not be used.

Note that preload may be accomplished with a larger number of smaller elastic devices. For example, such elastic devices may attach to the floated components at points adjacent to each sensor. In one embodiment, the perpendicular deflection of the sensor assembly is smaller than the deflection that will occur in the overlay or LCD panel 302 at points far from support. Thus, springs located very close to the sensors may have smaller unloaded displacements, less assembled energy storage, and substantially smaller size, and yet still divert insignificant touch force. In the situation just described, where the sensors are stiff compared to the touch surface, a preload spring near

one sensor will do little to load others. Therefore, it may be advantageous to use one preload spring per sensor.

An application bezel, such as application bezel 203, typically applies forces to a touch module such as touch module 101 or a display module such as display module 305. These will include static forces associated with assembly and seal maintenance, and variable forces from handling. A force-based touch system should be designed such that operation is not disturbed by these forces. In various embodiments of the present invention, components such as frames 104a and 104b receive and transmit these forces. For example, frame 104a may be provided with an elevated lip; that is, a vertical flange which rises above the level of touch surface 103 by a small amount. This facilitates use of an application bezel of simple design, that may have a flat and parallel undersurface, without danger of touching the overlay panel 102 (or, similarly, the floated LCD panel 302 in FIG. 3). In application, bezel forces applied to touch module 101 are transmitted directly to the surface below, which may be a very stiff LCD module. Thus by "borrowing" the stiffness of the surface below, frame 104a resists significant deflections. The bezel forces of greatest concern are predominantly perpendicular. Thus the greater section depth of frame 104b also allows the bezel forces to be successfully resisted in touch LCD 305 (FIG. 3), in spite of the use of thin material.

The thinness of the vertical legs of frames 104a and 104b maximizes the active touch area in relationship to the overall module dimensions. In touch LCD 305, for example, rearward placement of the force sensors, combined with the thinness of the vertical leg of frame 104b, allows the lateral dimensions of touch LCD 305 to be scarcely greater than those of an LCD with the same image size not equipped for touch. Since frame 104b

replaces a partial metal enclosure normally present, increase of width is limited to the introduction of a small clearance gap, plus any differential in material thickness. Since touch LCD 305 also avoids much or all of the increase in thickness usually associated with touch input, touch LCD 305 is of particular benefit in portable, or other space-constrained, applications.

Thus, in addition to other functions, vertical legs of frame 104a and 104b are seen to comprise application bezel support members.

In other variations of the invention, an additional application bezel support member may be provided, that both closely invests the force-sensitive structure, and that transmits application bezel forces to support behind. For instance, in one variation, a continuous rib or flange member may be molded into the application bezel. This flange member may extend perpendicularly downward from the undersurface of the application bezel, emerging from the lateral body of the application bezel along a line spaced slightly in from the visible edge of the bezel opening, and resting along its lower edge along the LCD display or other stiff support surface beneath. The height of the flange member is such as to provide necessary clearance between any inwardly protruding extension of the application bezel and force sensitive structures. The flange member may be fully continuous; however, it may also be interrupted into a sequence of segments or a row of bosses, closely enough spaced to "borrow" the necessary stiffness from below.

In another variation, an additional application bezel support member may comprise a vertical leg of a metal stamping coupled to, or part of, an LCD or other display assembly, but distinct from the vertical leg of frame 104a or its equivalent, while wrapping around and closely investing it. In yet another

variation, frame 104 may take the form of a "U" channel, with the interconnect and force sensors attached directly to the display surface just inside this channel. The inner vertical leg may then provide support for a lateral stiffening and restraint means, seal, and preload means, while the outer vertical leg comprises an application bezel support member.

In yet another variation of the invention, an additional application bezel support member may, while remaining laterally thin, be extended perpendicularly so as to closely invest an entire force-sensitive display structure or more, thereby achieving from depth of section greater stiffness against flexure from perpendicular bezel forces. Such member may then receive support for such forces from localized attachments to structures behind, or from other structures not constituting a continuous stiff surface of support.

In various embodiments of the present invention, the application bezel support member of the invention comprises a path for bezel support that closely invests force-sensitive structures; cantilevered support from the outer edges of an application enclosure is thus avoided, and disturbance to force-sensitive structures is minimized. A novel opportunity for forming an overall liquid and/or dust seal may also be thus obtained.

The lip of the vertical leg of frame 104a provides a line against which the application bezel 203 may achieve a dust and/or liquid seal, and also provides a convenient point of attachment for continuing a flexible liquid and dust seal from the frame 104a to the touch surface 103a. By providing a separation of the sealing function into an internal flexible seal and an external application seal, various embodiments of the invention simplify application assembly. The vertical frame leg also provides a point of attachment for a lateral stiffening

means (such as lateral stiffening means 108) which is close to the plane of touch. While the lateral stiffening means, lateral support means, and the sealing means are embodied within the same physical element in the particular embodiment depicted in FIGS. 1A-1B, FIG. 2, and FIG. 3, this need not be the case. In some applications, for example, there may be advantage in confining the lateral stiffening means and/or lateral restraint means to the vicinity of the sensors, where less vertical flexure is encountered, while distributing a thinner seal film around the entire periphery.

Various embodiments of the present invention advantageously reduce the introduction of touch location errors by tangential forces. For example, referring to FIG. 4, touch surface 103 (which may, for example, be the touch surface 103a shown in FIG. 2 or the touch surface 103b shown in FIG. 3) resides upon floated structure 401, which may represent, for example an overlay (such as overlay panel 102 shown in FIG. 1A) or display unit (such as LCD panel 302 in FIG. 3). A finger 402, applies a touch force comprising tangential component 403 and perpendicular component 404. Structure 401 is supported by a lateral stiffening means 405, and by force sensors 407 through lateral softening means 406. Receiving all forces is surrounding structure 408. Tangential component 403 of the touch force applied by the finger 402 generates reactions 409, and perpendicular component 404 of the touch force applied by the finger 402 generates reactions 410a and 410b. Due to the construction and positioning of lateral stiffening means 405, the combination of component 403 and reactions 409 generate no net moment. In the absence of such extraneous moments, then, the partitioning of the reaction to perpendicular component 404 between 410a and 410b accurately locates the touch position in

accordance with force and moment equations that are well-known to those of ordinary skill in the art.

Although lateral stiffening means 405, force sensors 407, lateral softening means 406, and surrounding structure 408 are illustrated in FIG. 4 in generalized form, it should be appreciated that these elements may be implemented, for example, as shown in FIG. 1A, FIG. 2, and FIG. 3. For example, lateral stiffening means 405 may be lateral stiffening means 108, force sensors 407 may be the force sensors shown in FIG. 1A, lateral softening means 406 may be lateral softening means 107, and surrounding structure 408 may be enclosure 202 and/or frame 104a or 104b. Note also that lateral softening means 107 may be provided below sensors 407, rather than above as shown, and also provide the desired function. Further, if the lateral stiffness of the force path through structure 401, sensors 407, and supporting structure 408 is low enough compared to that of the force path passing through lateral stiffening means 405, then lateral softening means 407 may be omitted.

Lateral stiffening means 405 is in part so named because it rests where a void might well exist in a conventional force-based touch device, while lateral softening means 406 is in part so named because it is inserted where a rigid coupling typically exists in conventional force-based touch devices. Note that in both cases, though, a coupling may be desired which is much stiffer to forces applied in one direction than to another at right angles. Columns, beams, plates, and membranes of high aspect ratio, for example, have this property, as do high aspect layers of elastomer trapped between rigid flat surfaces. Classical bearings do also, of course, but here it is better, as well as simpler, to avoid rubbing surfaces that may exhibit stiction at small force levels.

Some additional aspects should be noted which are not shown directly in FIG. 4. Lateral stiffening means 405 may also be present along the edges above and below the plane of the FIG. 4. In various embodiments of the invention, reaction forces 409 are developed primarily through shear in these other portions of lateral stiffening means 405.

FIGS. 5A, 5B, and 5C illustrate one embodiment of the lateral stiffening means 405. Generalized floating structure 401a, which may represent an overlay (such as overlay panel 102 shown in FIG. 1A) or display unit (such as LCD panel 302 in FIG. 3), receives perpendicular support from generalized force sensor 407 through lateral softening means 501, portrayed in this variation as an elastomeric sheet. Lateral stiffening means 502 is a sheet of material, with its freely flexing region intended to rest as close as possible to the plane of touch. Lateral stiffening means 502 may be carried around the full periphery of 401a, or may be confined to certain regions, such as those near the sensor mountings. There are two independent degrees of tangential force; one directed along the left/right axes of FIGS. 5A-5C, and tending to place the portion of lateral stiffening means 502 visible in these sections into tension or compression, and another perpendicular to the plane of FIGS. 5A-5C, and tending to place the portions of lateral stiffening means 502 visible in these sections into shear. If lateral stiffening means 502 is kept essentially flat, both degrees are effectively resisted by all portions of lateral stiffening means 502. For most of the materials of which lateral stiffening means 502 might be composed, the ratio of Young's modulus to the modulus of rigidity is such that about 3 to 4 times as much stiffening will come from portions of lateral stiffening means 502 in tension or compression as from equal lengths in shear.

Referring to FIG. 5B, perpendicular force 503 may cause a perpendicular deflection of touch surface 103 through distance 506, such that the flexing portion of lateral stiffening means 502 becomes tilted and stretched. This distance 506 may be particularly large at points midway between the support offered by the sensors, as is depicted in this cross-section. Tension in lateral stiffening means 502 rises as the square of distance 506. Due to the tilting of lateral stiffening means 502, this tension has a vertical component 504, which becomes part of the balancing reaction to applied force 503. This diminishes the reaction component 505, passing through the out-of-section sensors, to below the expected value, causing some error.

FIG. 5C depicts a situation in which the flexing portion of lateral stiffening means 502 is tilted in the absence of perpendicular load. Distance 510 may represent, for example, either an intentionally raised lip of frame 104, or the effect of component and assembly tolerances. Tangential force 507 causes compression in lateral stiffening means 502. Since this compression is tilted, it contains a perpendicular component balancing reaction 509, in addition to a tangential component that balances the tangential force 507. A similar situation in tension occurs along the opposing edge. Error force 509 and its equal but opposite counterpart acting upon sensors along the opposing edge, together represent a substantial moment generated in reaction to tangential force 507. This "jamming" effect represents another characteristic of the configurations depicted in FIGS. 5A-5C.

FIG. 6 depicts another lateral stiffening means 601, which is provided everywhere with a modest contour. Because lateral stiffening means 601 is compliant vertically (i.e., in a direction substantially normal to the touch surface 103), this contour allows surface 103 to be deflected substantially without

placing lateral stiffening means 601 into tension. This improves the range of touch forces which may be located accurately, especially for touches near the edge between sensors. The contour of lateral stiffening means 601 also greatly decreases the lateral stiffening effect in tension and compression. Since the lateral stiffness provided by the sides of lateral stiffening means 601 in shear may still be made sufficient, however, this is advantageous in greatly decreasing error from imperfections which have effect selectively through the tension and/or compression of the lateral stiffening means (referred to herein as the "jamming effect").

The structure of lateral stiffening means 601, and of others discussed here, may also be employed as lateral restraint means. In such use, contouring conveys similar benefits with regard to increasing the perpendicular range over which perpendicular stiffness is slight, while retaining a high ratio of lateral to perpendicular stiffness throughout.

Floating structure 401b is depicted with beveled edge 602. This allows the force sensors and the lateral stiffening means 601 to share the same narrow border width, while preserving clearance for the flexing portion of the latter. Application bezel 203 is depicted with additional feature 604 intended to guarantee clearance between the bezel 203 and both lateral stiffening means 601 and surface 103. Bezel 203 is depicted as carrying fully over the border structures, both to conceal them cosmetically, and to protect lateral stiffening means 601 from damage.

An additional point may be noted with regard to the contour of lateral stiffening means 601. The elastic axis of rotation for lateral stiffening means 601 in shear lies at the level of dashed line 603. For roughly circular contour, the offset of dashed line 603 from the plane of touch is approximately twice

the maximum offset of lateral stiffening means 601 itself. If the contour of lateral stiffening means 601 were that of a shallow "V," dashed line 603 would lie at the level of its point. Since the plane of accuracy lies at the level of dashed line 603, tangential force rejection is not perfect; it is, however, still substantial.

FIGS. 7A-7C depict additional variations 108a-c of the lateral stiffening means 108, as may be applied, for example, to the first and second embodiments depicted in FIGS. 1A-1B, FIG. 2, and FIG. 3. In these variations, frame 104 is depicted with an intentional elevation, or lip, which may rise 0.020 in. above touch surface 103. Lateral stiffening means 108a also acts as a seal and is provided with a fairly abrupt "dog leg" contour 701a. Most of the flexing region of 108a is backed up by overlay 102. This portion achieves the advantage of becoming quite resistant to damage, and need not necessarily be covered by the application bezel 203a. It should be appreciated that in other embodiments, lateral stiffening means 108a may not provide a seal between frame 104a and touch surface 103.

In FIG. 7A, contour 701a is placed close to the point 702 at which lateral stiffening means 108a attaches to surface 103. Bezel 203a is of minimal width. Lateral stiffening means 108a may be opaque, and of a color suitable for a visible detail of the border. Note that there is little or no exposed cavity under the bezel 203a where contamination may collect, so that this arrangement may be particularly suitable for dirty environments. In FIG. 7B, contour 701b is placed close to the lip of frame 104. Bezel 203b is depicted concealing the border structures. Lateral stiffening means 108a and 108b in FIGS. 7A and 7B, respectively, may be applied as, for example either four separate tapes, or as a single die cut piece.

For the dog-leg lateral stiffening means 108a-b of FIGS. 7A-7B, the elastic axes 603 for rotation in reaction to shear lie at approximately the average height of the flexing portion of the lateral stiffening means above touch surface 103. The resulting plane of accuracy may be sufficiently close to the touch plane for many purposes. Note, however, that any residual jamming effect tends to put the plane of accuracy below the touch surface 103, whereas the axes 603 here lie above it. Thus by adjusting the position of contour 701 and/or the lip height, the two opposing effects may be adjusted to cancel out. This constitutes one example of a lateral stiffening means that creates tangential reaction forces much more closely confined to the plane of touch than is the lateral stiffening means itself.

In FIG. 7C, lateral stiffening means 108c comprises a transparent film which passes over the entire touch surface 103. The area of lateral stiffening means 108c interior to the point of attachment 702 is fastened with optical adhesive. If bezel 203a is minimal as shown, and if floating structure 401 is otherwise transparent, it may be cosmetically advantageous to coat the upper or lower surface of floating structure 401 along the edges with opaque material (so as to conceal sensors and other edge structures from user view). If floating structure 401 is a glass overlay or fragmentable display, lateral stiffening means 108c provides an advantageous safety effect in case of breakage. Since surface 103 is of uniform optical quality right up to the point of attachment 702, this point may now be placed farther inward without increasing the border width. Since the full border width is now available for the flexing portion of 108c, the advantage is gained that the lateral stiffening means 108c may now be made thicker, and therefore tougher, without giving it excessive perpendicular stiffness.

Turning to FIG. 8, molded plastic bezel insert 801 carries transparent protective film 802. Flange 803 on insert 801 engages slot 804 in application bezel 203b. Together, insert 801, film 802, and bezel 203b provide a liquid/dust seal. Film 802 also protects the upper surface of structure 401 from scratches, especially if it is a plastic overlay or an LCD polarizer film. If 401 is a bare glass overlay, film 802 provides some protection from shards in case of breakage. The combination of insert 801 with protective film 802 constitute a part easily replaced in the field. Tiny holes 805 are present at the center of each side, and provide purchase for a needle or pointed tool to draw the insert inward out of slot 804. Flange 803 and slot 804 are engaged maximally at the mid sides, but taper to negligible engagement at the corners to facilitate replacement.

Touch pressure brings film 802 into firm contact with the surface of 401 under the point of contact, allowing the touch module below to locate the point accurately. Film 802 may be made quite thick, since perpendicular force transmitted to its attachment at 801 does not generate a reaction force passed to 401. That is, there is no analog to the problem depicted in FIG. 5B. Lateral stiffening/restraint means 806 is also provided, but this no longer need perform a combined seal function, and may be implemented in a wide range variations.

Turning to FIGS. 9A-9B, a larger sensor according to another embodiment of the invention is depicted. Principal element 106b is made from spring steel strap 1/4 inch wide and 10 mils thick. This is cut to a length of 3/4 in. and pressed in a die to the shape shown. The capacitive gap is 5 mils, but has been drawn with some exaggeration for clarity. The free span of principal element 106b is 550 mils, the central 300 mils of which are opposed by land 114. A substantially planar

support surface is found on the epoxy glass PC board 901, which is only slightly larger than principal element 106b. Discrete wiring 105b provides interconnection. PC board 901 is mounted against underlying support 408 with segments of acrylic tape 902, which also constitute a lateral softening means. PC board 901 is of sufficient stiffness that lateral softening means may be placed thereunder. This configuration has the advantage that should support 408 flex, its curvature is very poorly transmitted to board 901, thus preventing enclosure forces from disturbing force readings. Pivoted force bearing 121b is in the form of a ridge, and suffices to fix sensor sensitivity, while providing good strength against extreme overloads. Unloaded capacitance is about three picofarads, and the bottoming-out force is between four and five pounds.

Although the use of different materials may require other choices of dimensions, the principal element 106b may be made from other materials, such as plastic with a electrically conductive coating.

Turning to FIGS. 10A-10B, a smaller sensor according to one embodiment of the invention is depicted. Principal element 106 is cut from spring steel 6 mils thick. It is 120 mils wide and 230 mils long. Alternatively, principal element 106 may be of phosphor-bronze 8 mils thick, with the same length and breadth. The capacitive gap is 1 mil, formed by spacing the gap with a temporary shim while lands 113 are reflowed with solder. Alternatively, the solder may contain particles of controlled size that act to space the principal element 106 from lands 113.

Bearing dimple 121 may be created with a spring-loaded center punch while principal element 106 is pressed against an aluminum backing. The free span of principal element 106 is 150 mils, the central 86 mils of which are opposed by land 114.

Unloaded capacitance is about three picofarads, and the bottoming-out force is between three and four pounds.

Other details of assembly are as described for the sensors shown in FIG. 1A.

Capacitive force sensors exhibit a change in capacitive reactance as a function of a change in applied force. For the sensors of FIGS. 9A-9B and 10A-10B, this change is substantially linear for smaller forces, where the relative gap change is small. With larger forces, however, the center of the capacitive region closes up while the edges remain more widely spaced; this leads to a drop in reactance that becomes more rapid than linear. To increase the range of force sensing that may be accomplished with high accuracy, compensation for the response characteristic just described may be accomplished in the processing of the sensor signal; alternatively, varied embodiments of the sensor of the invention may be provided which have an inherently greater range of linear reactance change.

Thus in another novel aspect of the invention, a capacitive force sensor of nonuniform gap may provide improved linearity of measurement with simple processing of the signal, even where one or more capacitor plates are flexing in response to applied force.

For example, FIG. 11 depicts a sensor 1100 with overall dimensions similar to those of the sensor of FIGS. 10A-10B. Principal element 106c, however, has been provided with a slight bend of controlled shape. Because this bend would otherwise be too subtle to depict with clarity, the vertical dimensions of the sensor 1100 are exaggerated tenfold in FIG. 11 with respect to the sensor's horizontal dimensions. The bend is such that the ends of element 106c may attach to lands 113 with a minimal solder film, while the center provides a maximum capacitive gap

(between point 1102 and the upper surface of land 114) of about 1.5 mils.

There is a level of force that may be applied to coupling 121c which is just sufficient to first bring element 106c into contact with the land 114. The tapering of the capacitive gap away from the exact center point 1102 of element 106c may be so shaped that this contact tends to happen simultaneously at all points where element 106c opposes land 114.

Such a nonuniform gap design may help to provide a force sensor with optimal linearity. Call a general applied force "F", and call the minimum force to bottom out the sensor "F_max". Subject to the assumptions that the gap is thin compared to its lateral dimensions, and that Hooke's law applies, the stated condition upon the gap shape requires that the gap spacing be everywhere proportional to F_max - F. Each small region then adds to the total capacitance a contribution proportional to 1/(F_max - F). This expression of the functional dependence upon applied force is not itself a function of position, and so factors out of the area integral defining the total capacitance. The overall sensor capacitance thus varies in proportion to 1/(F_max - F), and its capacitive reactance at a given frequency is proportional to F_max - F. This is, of course, the expected behavior for an ideal parallel plate capacitor spaced by an ideal spring. Thus a linear measure of the perpendicular force transmitted may be obtained by differencing the reactance before and during a touch, for the full range of gap closure.

Principal element 106c is substantially rectangular and of uniform thickness, and is mounted rigidly at its ends through lands 113 to interconnect 105 or other support. Also, all deflections to be considered are small compared to the thickness of element 106c. Therefore, perpendicular force applied to

coupling 121c will deflect element 106c in a pattern closely approximating that of a centrally loaded uniform beam with clamped end constraint. This deflection pattern may be expressed as $d \cdot (3 \cdot x^2 - 2 \cdot x^3)$, where *d* is the maximum deflection, and *x* is the fractional position along element 106c, measured from the last clamped point 1101, where $x = 0$, to the center of element 106c at point 1102, where $x = 1$. The curve from point 1102 to point 1103 then continues as the mirror image of this.

The desired shape for element 106c in its unloaded condition is, therefore, the negative of this deflection pattern, extended with flat ends for mounting. In cases where the end constraint has significant rotational flexibility, the correct shape for element 106c may be derived from the stated deflection pattern by associating with point 1101 a value of *x* that is somewhat larger than zero. In the limiting case of simply supported ends, $x = 0.5$ may be assigned to point 1101, while $x = 1$ is still assigned to point 1102.

For convenience of exposition, the curve for element 106c has been defined here over the entire span between attachments at point 1101 and point 1103. Only the area of element 106c opposing the second capacitor plate (i.e., land 114) needs to follow this curve, however, so long as other regions do not bottom out before the capacitive areas do.

Although providing substantial improvement, this one-dimensional analysis is not fully precise, given that coupling 121c approximates a point feature, rather than a linear one as does bearing 121b of FIGS. 9A-9B. Further degrees of refinement, however, may be obtained as desired through methods of analysis well known in the art, as well as by empirical means. Such methods may also be similarly employed to linearize the reactance response of a wide range of other capacitive force

sensor variations that fall within the scope of the invention. Such variations include, for example, complex outlines, nonuniform thickness, flexure in one capacitor plate or both, multiple areas of support or single cantilevered support, etc. In all cases, the desired effect is achieved by shaping the surfaces of one or both capacitor plates to produce a gap that "bottoms out" simultaneously at all points.

Turning to FIGS. 12A-12D, additional outline and mounting arrangements of force sensor principal elements are shown according to various embodiments of the present invention. All of the elements shown in FIGS. 12A-12D may, for example, be made with uniform thickness. Principal elements 106d, 106e, and 106f provide regions variously narrowed so as to concentrate flexure in areas 1203a-c not serving as capacitor plates. This reduces flexure in capacitive areas 1202a-c, improving linearity of reactance change. Couplings 121d-f receive perpendicular force, which is passed to structures beyond via support areas 1201a-c. With the thicknesses of the principal elements 106d-f being greater, for a given stiffness, than elements of similar size without narrowed regions, clamped support of areas 1201a-c may receive less concentrated twisting stress. Conversely, the concentration of flexure into areas 1203a-c means that simple support of areas 1201a-c will see greater rotation. Couplings 121d-f may be elevated features as described previously, elastic features as described below, or any other coupling feature providing a defined path for entrance of the force to be measured.

Referring to FIG. 12C, principal element 106f is provided with three areas of support 1201c, whereas principal element 106g (shown in FIG. 12D) is a simple cantilever with a single area of support 1201d. Cantilevered element 106g must, of course, receive clamped support in area 1201d; whereas the other

elements 106d-f may be adapted for either simple or clamped support in areas 1201a-c, respectively.

Turning to FIGS. 13A-13B, additional variations for the cross-sectional shape and thickness of a principal element of a force sensor are shown according to embodiments of the present invention. For example, referring to FIG. 13A, a sensor 1300 is shown according to one embodiment of the present invention. The vertical dimensions of the sensor 1300 (and the sensor 1310, shown in FIG. 13B) are exaggerated approximately tenfold in FIG. 13A with respect to the sensor's horizontal dimensions. Principal element 106h has relatively thin regions 1303 between mounting regions 1301 and capacitive region 1302. These may be produced from planar feedstock by a process such as, for instance, coining. They may again serve to reduce the relative amount of flexure in capacitive area 1302, thereby improving linearity. Referring to FIG. 13B, principal element 106i of sensor 1310 achieves a similar relative stiffening of capacitive region 1302 by laminating this portion. As depicted for principal element 106h, a principal element relatively thicker in support regions 1301 may advantageously reduce stress in the support attachments caused by the moments passing through them.

Referring to FIGS. 14A-14C, an embodiment of a sensor according to another embodiment of the present invention is depicted in which the principal element is simply supported, and in which the second element is a discrete element of identical manufacture to the principal element.

More specifically, turning to FIG. 14A, principal element 106j (shown in solid outline) may be 300 mils wide and may be stamped or photoetched from beryllium-copper 15 mils thick. Tabs 1401a-b engage plastic spacers 1402, allowing principal element 106j to be assembled opposite another identically

manufactured element 1403, which, flipped end-for-end with respect to 106j, is inserted into the same pair of spacers 1402.

FIG. 14B presents a side view of plastic spacer 1402. Rectangular holes 1404a receive tabs 1401a of one element (such as element 106j), while rectangular hole 1404b receives tab 1401b of the opposing element (such as element 1403). Elevations 1405, on the sides of the spacers 1402 away from the principal element 106j, locate the force sensor by engaging holes (not shown) in the support surface. Thus at one end of the force sensor, the support surface corresponds to the plane of 1406a, and at the other, of 1406b.

FIG. 14C presents a partial cross-section in which principal element 106j and element 1403 are employed as a force sensor in a touch location device. Spacers 1402 are employed above and below the plane of section, and seat against the immediate support surface provided by outer frame 104c. Transparent touch overlay 1408 is secured within the inner frame 1407 by cement 1411. The combination is then supported perpendicularly by plastic force transmission couplings 121h, one of which is associated with each sensor. Couplings 121h may be press fit into holes in inner frame 1407, which align over the centers of the square capacitive areas afforded by each of the principal elements 106j employed. Inner frame 1407 is supported laterally by combination seal and lateral restraint means 1409. Oversize clearance holes may be provided in inner frame 1407, if necessary, to guarantee that there is no contact with the unused elevations 1405 that are on the surfaces of spacers 1402 directed upward. Discrete wiring 1410 may connect to the upper surfaces of tabs 1401 by soldering or wire welding. Application bezel 1412 seats against lateral restraint means 1409 and frame 104c.

When unloaded, principal element 106j rests about 10 mils above the surface of non-flexing element 1403. Holes 1404a-b are somewhat larger at the surface of spacer 1402, and taper to minimal cross-section at its center, which cross-section just matches tabs 1401a-b. Thus as force is applied to coupling 121h, principal element 106j flexes as a member having simply-supported end constraint with minimal friction.

The arrangement of FIG. 14C offers a touch location device of minimal thickness, but the inclusion of inner frame 1407 increases border width. The sensor is scalable to other, including smaller, sizes.

Since principal element 106j may be located quite close to the plane of touch, special provisions for handling tangential forces may be omitted without significant adverse consequences. For instance, the aggregate lateral stiffness of lateral restraint means 1409 need not substantially exceed the aggregate lateral stiffness of the force sensors and their couplings 121h. Nevertheless, it should be noted that lateral restraint means 1409 provides a novel means of lateral assembly alignment having high perpendicular compliance.

We now consider sensors of a type made in accordance with embodiments of the invention where the principal element is made of an insulating material with a conductively coated area or areas.

Turning to FIG. 15A, epoxy glass PC board 1501 includes a region comprising principal element 106k. Principal element 106k comprises lands 113 and 114, and such portions of the epoxy glass substrate as store significant elastic energy associated with changes in the capacitive gap.

As may be seen more clearly from cross sectional FIG. 15B, a predefined path carries applied force from touchable structure 401, through force-coupling elastomeric pad 121i, upper

capacitor plate 1503, and spacing/connecting solder film 1505, to central region 1506 of principal element 106k. Central region 1506 is flanked by slots 1502, which serve both to increase and to relatively localize the flexure in the PC substrate. From central region 1506, force passes both out and around the ends of slots 1502, eventually reaching PC board supports 1504. As force passes away from the immediate vicinity of the capacitive area and the slots 1502, any additional flexure it produces ceases to relate to force-induced changes in the capacitive gap, and so is no longer passing through the force sensor. If present, supports 1504 placed close to the sensor may have some effect upon sensitivity and symmetry of response. Such close supports may be given a symmetrical disposition, such as that shown, not excessively close to central region 1506. More remote supports may be placed in any pattern desired.

Elastomeric pad 121i provides both lateral softening and a degree of rotational softening. As such, pad 121i may serve as an alternative to the combination of raised feature 121 and lateral softener 107 shown in FIG. 10B. Pad 121i may be fastened adhesively to the capacitor plate 1503 below, but not attached above. Structures above may then be aligned and preloaded shown as elsewhere herein. Alternatively, pad 121i offers the possibility of maintaining alignment and assembly through adhesive attachments both above and below.

The variation presented in FIG. 15C alters the force path, as it now passes through the length of the upper capacitor plate 1503. This upper plate 1503 may now make a significant contribution to the elastic energy storage associated with the capacitive gap; in which case, it is appropriate to view the upper plate 1503 as an additional principal element 106q, working in concert with lower principal element 106m. Force

passes from element 106q through solder 1505b into element 106m, continues around slots 1502, into central region 1506, and thence to support 1504b.

Thus, many variations on the capacitive force sensor of the invention will be evident to one of ordinary skill in the art. These variations may share certain features, such as:

Major components of the sensor may be substantially planar, and may be manufactured from planar materials. This provides inexpensive access to high-precision flat surfaces, and to surfaces that are designed to deviate from flat by slight but precisely controlled amounts. Sensors according to various embodiments of the invention may involve one or more substantially planar principal elements. These receive and pass on forces through a predefined path, and respond to the normal component of such forces by a normal displacement of a capacitive surface that they expose. The capacitive surface so exposed may itself be subject to some degree of flexure. Note that the point at which force enters a principal element may be considered to be that point beyond which force transmitted may produce flexure directly affecting the measured capacitive gap.

Sensors according to various embodiments of the invention may have a very small gap; for this reason, in part, they may be made small in comparison with the containing touch location device. The gap-defining mechanical path of such sensors is small compared to the dimensions of the touch location device; as a direct result, the gap suffers only tiny error deflections due to device flexure. Furthermore, the small size of the gap-defining path may effectively provide additional error reduction through local stiffening and/or structural isolation.

To more precisely understand the meaning of the term "gap-defining path" as used herein, draw a curve through space that originates at the center of one capacitive area and terminates

at the center of the opposing capacitive area. Pass this curve entirely within solid material fully contributing to the mechanical coupling between the two opposing capacitive areas. The term "gap-defining path" refers to the length of the shortest such curve.

In sensors according to various embodiments of the invention, the extent of the gap-defining path projected along a line normal to the sensor (referred to herein as the aggregate normal component of the gap-defining path) may be scarcely greater than the thickness of the gap itself. Since the sensor spring lies in the same plane as its corresponding capacitive area (e.g., both are embodied in the principal element 106), and is a continuation of the same planar material defining the plane of that area, some means of directly spacing the width of the gap is all that may be required to construct the capacitor. In prior art designs of capacitive force sensors, wherein the normal component of the gap-defining path is substantially larger than the gap itself, the gap is effectively determined by the small difference of two larger numbers. This has previously limited the precision, stability, and economy with which a very small gap may be employed.

The precision with which the directly-spaced gaps of sensors of various embodiments of the invention may be made allows for a capacitive gap of high aspect ratio. Width and length that are large compared to the gap spacing itself allow an adequate absolute capacitance to be maintained as the sensor is miniaturized.

In some embodiments, some original material may be removed from regions of originally substantially planar materials. Thus, 1 or 2 mils of copper may be etched from between the support lands 113 and counter-electrode land 114, to isolate them electrically. The surfaces of lands 113 and 114 remain

highly coplanar, however. Thus, in spite of this, and similar operations that may be performed between the capacitive and support areas of substantially planar principal elements 106, which operations may superficially increase the normal component of the gap defining path, the end surfaces continue to afford the same opportunity for establishing highly precise, directly-spaced gaps using offsets or spacing means of roughly the same perpendicular extent as the gap spacing itself.

Capacitive force sensor stiffness in the direction of measurement may be inversely related to the gap width. Thus, sensors according to various embodiments of the invention provide very high stiffness, raising the resonant frequencies of the supported structure and improving the performance of the unit housing the force sensor. Keeping sensor motions very small also reduces the problem of force transmission on parasitic paths (those not passing through a sensor).

Some variations of the sensor of the invention further exploit an interconnect, such as a PC board, to provide both a substantially planar support surface and coplanar second capacitor plate for a principal element.

It is to be understood that although the invention has been described above in terms of particular embodiments, the foregoing embodiments are provided as illustrative only, and do not limit or define the scope of the invention. Other embodiments are also within the scope of the present invention, which is defined by the scope of the claims below.

What is claimed is: